Research and Development of Autonomous Distributed Power System and Contribution to Regional Decarbonization

Kotaro Jinushi＊1
OES Project, Planetary Navigation Group
Sony Computer Science Laboratories, Inc.

Daisuke Kawamoto＊2
OES Project, Planetary Navigation Group
Sony Computer Science Laboratories, Inc.

1. Introduction

At Sony Computer Science Laboratories (Sony CSL), we are promoting the introduction of renewable energy through research and development of the Open Energy System™ (OES)—namely, a concept that will form the basis of distributed power systems using distributed renewable energy and change the nature of society. The contents of this research and development, examples of demonstration experiments, and future developments are described hereafter.

2. Background of the need for distributed power systems

As reaffirmed in the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), which is the intergovernmental organization that collects and organizes scientific studies on global warming, climate change is being driven by global warming[1]. Countries are also increasingly moving to counter carbon-dioxide emissions, which are closely related to global warming.

Japan can be taken as an example country. In October 2020, Japan's Prime Minister Suga announced the policy goal of reducing emissions of greenhouse gases such as carbon dioxide to virtually zero (so-called "carbon neutrality") by 2050. To achieve this goal, the energy-conversion sector (primarily power generation by power plants)[2], which emits the largest amount of carbon dioxide by sector, must be decarbonized; that is, power generation must stop depending on burning carbon-dioxide-emitting coal, natural gas, etc. In fact, the Sixth Strategic Energy Plan approved by the Japanese Cabinet in October 2021 clearly states that renewable energy must be introduced to the maximum possible extent.

As pointed out in the Net Zero 2050 report[3] of the International Energy Agency (IEA), which makes policy recommendations on energy issues in general, to achieve decarbonization by 2050, it will be necessary to (i) shift from conventional fossil fuels (which emit CO_2) to renewable-energy sources such as solar and wind power and (ii) make maximum use of those sources. These renewable-energy sources are also called "variable renewable energy" in a way that indicates the amount of electricity generated by them fluctuates with variable weather and other factors. As for electricity systems, it is essential that supply (generation) and demand (consumption) always match. It is therefore necessary to be able to balance the fluctuating amount of electricity generated by renewable-energy sources with demand.

As one renewable-energy source, solar-power generation benefits from ease of introduction, so it will be installed in various places. In conjunction with this trend, the nature of electricity-transmission networks will also change. Conventionally, large-scale power plants were built far from the power-consumption areas. From the power plants, electricity only flowed one-way via transmission lines toward the consumption areas. As stated in the Sixth Strategic Energy Plan, since fewer suitable sites are available for construction of large-scale solar power plants, it is necessary to install solar-power-generation facilities on the roofs of houses, on idle land in municipalities, and in various other locations where solar power has not been introduced before. As a result, power will flow "in" from the extremities of the power network in a manner that was not previously anticipated. Dealing with this new trend will also be a challenge.

3. Our approach

As for transitioning the electricity system to generation from renewable-energy sources and promoting decarbonization, two issues must be addressed: (i) coordinating the ability to balance supply and demand and (ii) managing the new electricity network. Sony CSL has focused on "microgrids" as a mechanism for utilizing distributed renewable energy. A microgrid is a distributed power system that enables control of the balance between demand and consumption in a small, regional (community size) basis, stable operation of the electricity system, and connection with existing power systems. A microgrid is a distributed power system that generates, stores, and distributes the electricity consumed within a certain area while being able to adjust locally. OES is a concept centered on a distributed power system that utilizes this microgrid mechanism to maximize the use of renewable energy and achieves regional energy circulation. As for the core technology of OES, we have developed the "autonomous power interchange system" (APIS), which is a control technology that establishes a microgrid by autonomously matching supply and demand on a one-to-one (peer-to-peer) basis and flexibly adapting

---

＊1 Kotaro Jinushi's affiliation is as of January 2023.
＊2 Daisuke Kawamoto's affiliation is as of January 2023.

the power supply by utilizing storage batteries connected by DC private lines.

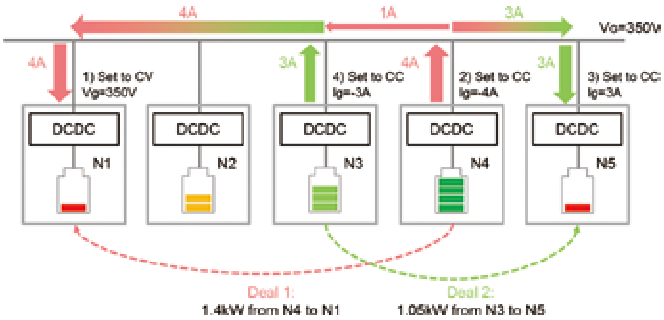
4. Our technology

As explained below, APIS consists of two technologies: (1) physical peer-to-peer power interchange and (2) autonomous distributed cooperative control.

(1) Physical-peer-to-peer (PP2P) power interchange

A feature of this technology is that power is interchanged between storage batteries by using constant-current control to adjust the power balance between the storage batteries. In the case of conventional power interchange using voltage control, it is difficult to achieve quantitative power interchange within a single power network. Constant-current control enables PP2P power interchange through flexible battery combinations such as many-to-many, one-to-many, and many-to-one, so it becomes possible to adjust the balance between demand and supply. PP2P power interchange between five storage batteries in a DC power network is shown schematically in Figure 1.

■ **Figure 1: PP2P power interchange**



(2) Autonomous distributed cooperative control

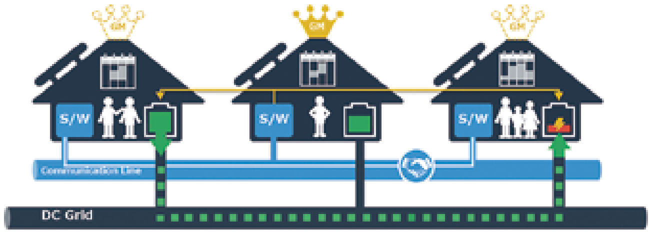
As for APIS, each storage battery is controlled by software with the same functions. The software transfers power according to the trading conditions set for the storage batteries, i.e., target SoC (state of charge) for each time period, amount of electricity to be interchanged, electricity prices, etc. (hereafter, simply "conditions"). Each storage battery periodically compares its "conditions" with the target SoC and offers to interchange power flexibly with the other storage batteries. The battery receiving the offer checks its SoC and other conditions and decides whether to accept the proposal. If it accepts the offer, a deal will be concluded, and power will be interchanged (Figure 2). This conditions for each storage battery can be set in units of time. The conditions can be changed all at once from the server side. While each storage battery can autonomously perform power interchange, it is also possible to control power interchange from the APIS control center side.

Combining these two technologies has the following two benefits.

Effective use of renewable energy: By exchanging power between storage batteries, it is possible to adjust the supply-and-demand balance of renewable energy (the amount of which is generated is expected to fluctuate) and use it effectively.

Regional circulation of energy: Controlling the charging and discharging of individual storage batteries by using APIS makes it possible to collect surplus electricity within a certain region at specific facilities. It will also be possible to transfer surplus electricity to the large batteries of EVs and transport it to the place that it is needed in a manner that achieves "energy circulation" within the region.

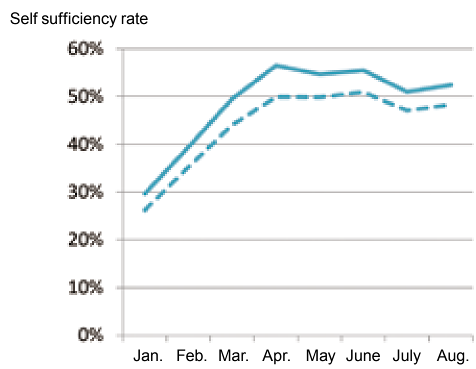
■ **Figure 2: Autonomous distributed control of household power supply by APIS**



5. Example demonstration of OES

We first tested APIS at 19 residences for teachers on the campus of the Okinawa Institute of Science and Technology Graduate University (OIST). Solar panels and storage batteries equipped with APIS were installed at each residence and operated from December 2014 to March 2020. (This demonstration experiment was selected as Okinawa Prefecture's "Subtropical Island-type Energy Basic Technology Research Subsidy Project" and was conducted as a joint venture with OIST, Okisokou Co., Ltd., and Sony Business Operations Corporation). This experiment demonstrated that a new distributed power system can be constructed in parallel with the conventional power system, operate stably, and consume more renewable energy than simply installing solar panels and storage batteries at each home (Figure 3).

■ **Figure 3: Effects of power interchange in Okinawa**



Simulation from OIST's actual data (from 2015)

APIS can be constructed relatively easily by connecting each storage battery with a private DC line. However, installing new private DC lines faces issues such as high installation cost, which limits the locations where they can be installed. With that issue in mind, we are expanding and demonstrating APIS to enable power interchange similar to that described above by utilizing AC distribution lines that are already installed.

The location of the expanded demonstration of APIS is Umaba School Cottage, a "workcation" facility in Shiraji Umaba, Ikeda-cho, Miyoshi City, Tokushima Prefecture (Figure 4). Since October 2021, a power-interchange demonstration experiment using storage batteries (Figure 5) connected to the AC wiring of this building has been conducted in collaboration with the Consortium for the Creation of Environmentally Friendly Workation Models, a consortium of industry, government, and academia.

■ Figure 4: Umaba School Cottage and solar-power generation

■ Figure 5: Installed storage batteries (Murata Manufacturing Co., Ltd.)

At the same time, we are verifying the charging and discharging of fixed amounts of electricity from EV storage batteries via CHAdeMO using ECONET-Lite. In 2023, a battery-storage system and expanded APIS were installed at other facilities in the city. We plan to implement two-way power interchange between multiple points (i.e., those facilities) by using an actual power-distribution network and EVs.

We want to demonstrate that this battery-storage system and expanded APIS can be used to effectively utilize renewable energy, contribute to the decarbonization of the region, and promote the circulation of energy within the region by supplying surplus daytime solar power generated by households in the region to community centers that consume electricity during the daytime.

6. Future developments

Our goal is to implement a new distributed power system, mainly based on renewable energy, to promote decarbonization and increase regional energy independence. To help achieve this goal, APIS was released on an open-source basis in December 2020[4]. We hope that this open-source release will promote open innovation and that we can introduce APIS widely. We are also thinking about redefining APIS for matching surpluses and shortages of various goods and expanding it into a system that combines excess and shortages in the flow of goods and people within a certain area in a way that makes efficient use of them.

For example, when EVs are recharged in areas with electricity surpluses and transported to places with electricity deficiencies, people can be transported in those EVs, thereby contributing to secondary transportation in those areas. We are also considering combining APIS with smart agriculture. When the timing and quantity of agricultural crops to be harvested are estimated, if a surplus of agricultural produce is estimated, it can matched with the demand of organizations within the region and supplied to them. We believe it is possible to expand APIS to such an intra-regional distribution system. Pursing these kind of distributed systems that are not limited to electricity, and their social implementation, cannot be achieved by Sony CSL alone. We therefore strongly desire to promote APIS while co-creating it with various organizations.

(This is a translation of the January 2023 issue of the ITU Journal)

References

[1] IPCC Sixth Assessment Report First Working Group Report, https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

[2] JCCCA 4-04 Carbon-dioxide Emissions by Sector in Japan (2020), https://www.jccca.org/download/65477?parent=chart&p_page=3#search (viewed 2022/11/17)

[3] IEA Net Zero by 2050 https://www.iea.org/reports/net-zero-by-2050

[4] Sony CSL APIS https://github.com/SonyCSL/APIS